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DISCUSSION OF BASE COURSE DRAINAGE FOR AIRPORT PAVEMENTS

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By Edward S. Barber, D. P. Krynine, and
A. Casagrande and W. L. Shannon

SOIL MECHANICS AND FOUNDATIONS DIVISION

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DISCUSSION

EDWARD S. BARBER,[3] A. M. ASCE.—The field and laboratory data presented are very worthwhile. Some simplification of the theoretical development could be effected by considering the cross section and gradient at x in Fig. 3, assuming that the slope of the base is fully reflected in the hydraulic gradient. Thus, as an alternative to Eq. 9*c*

$$dq = k\,H\left(\frac{H}{c_3\,x} + \tan\alpha\right)dt \quad \ldots\ldots\ldots\ldots\ldots\ldots (17)$$

For a steady state with $x = L$ and using $c_3 = 2$, from Dupuit's formula for a horizontal base, this gives

$$k = \frac{q\,L}{H\left(\frac{H}{2} + L\tan\alpha\right)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (18)$$

If Eq. 18 were used instead of Eq. 9*b*, Col. 6 in Table 1 would read 9, 0.09, 13, and 0.22, which compares better with the flow net analysis values in Col. 5 Table 1.

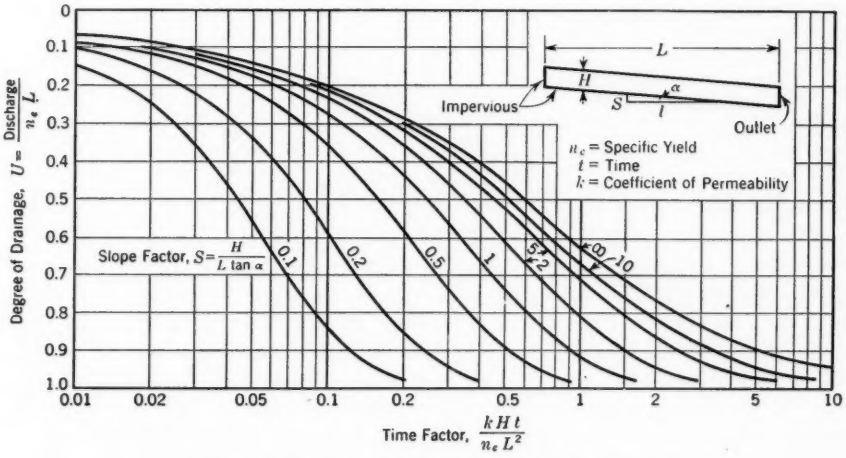

FIG. 19.—RATE OF DRAINAGE OF FLOODED BASE COURSE

Integration of Eq. 17 and substitution of $c_3 = 2.4$, as indicated by laboratory tests with a horizontal base, gives

$$\frac{t\,k\,H}{n_e\,L^2} = U\,S - 0.48\,S^2\log\left(1 + \frac{4.8\,U}{S}\right) \quad \ldots\ldots\ldots\ldots (19a)$$

NOTE.—This paper by A. Casagrande and W. L. Shannon was published in June, 1951, as *Proceedings-Separate No. 75*. The numbering of footnotes, tables, equations, and illustrations in this Separate is a continuation of the consecutive numbering used in the original paper.

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for $0 \leqq U \leqq 0.5$. Similarly for $0.5 \leqq U \leqq 1$:

$$\frac{t\,k\,H}{n_e\,L^2} = 0.5\,S - 0.48\,S^2 \log\left(1 + \frac{2.4}{S}\right) + 1.15\,S \log \frac{S - U\,S + 1.2}{(1 - U)(S + 2.4)} \quad (19b)$$

Eqs. 19 are plotted in Fig. 19. For $U = 0.5$ the following approximate formula is useful

$$t_{50} = \frac{n_e\,L^2}{k\,H} \frac{0.44}{0.74 + \frac{1}{S}} \quad (20)$$

in which t is time, n_e is specific yield, and k is the coefficient of permeability. Comparison with the recommended calculation indicates that $c_3 = 2.4$ for all values of S as illustrated in Table 2.

TABLE 2.—COMPARATIVE VALUES OF $\frac{t_{50}\,k\,H}{n_e\,L^2}$

Slope factor S	Procedure I	Equation 19a	Equation 20
0.5	0.16	0.16	0.16
2	0.34	0.34	0.35
10	0.49	0.51	0.52

The fact that some dense-graded base course materials have been found satisfactory even though they are not drainable according to the criterion proposed in the paper suggests that it is possible to have a material dense enough so that it is stable even though wet or frozen and thawed.

D. P. KRYNINE,[4] M. ASCE.—As the authors state, the purpose of their paper is (1) to analyze the conditions under which base courses become saturated and (2) to develop and test a procedure for the design of base drainage. The writer's comments refer to some features of these two items.

Saturation of Base Courses.—In addition to two causes of base-course saturation as suggested by the authors (that is, frost action and pumping of water from lower strata, and infiltration through the pavement) at least two more should be considered—(*a*) continuous water vapor and, sometimes, capillary moisture movement from the water table, and (*b*) transmission of moisture through air with subsequent condensation and horizontal capillary motion. The latter cause has been discussed elsewhere[5] by the writer. Cases are on record[5] of pavement failure caused by the accumulation of moisture in the base course, even in desert regions. Important information on the saturation of the base courses has been collected by L. D. Hicks. Unfortunately, only an abbreviated version of Mr. Hicks' findings has been published.[6] Important work in this field has also been done by Miles S. Kersten,[7,8] A. M. ASCE.

[4] Cons. Engr., San Francisco, Calif.

[5] Discussion by D. P. Krynine of "Development of CBR Flexible Pavement Design Method for Airfields, a Symposium," *Transactions*, ASCE, Vol. 115, 1950, p. 572.

[6] "Observations of Moisture Contents and Densities of Soil Type Bases and Their Subgrades," by L. D. Hicks, *Proceedings*, Highway Research Board, National Research Council, Vol. 28, 1948, p. 422.

[7] "Survey of Subgrade Moisture Conditions," by Miles S. Kersten, *Proceedings*, Highway Research Board, National Research Council, Vol. 24, 1944, p. 497.

[8] "Subgrade Moisture Conditions Beneath Airport Pavements," by Miles S. Kersten, *Proceedings*, Highway Research Board, National Research Council, Vol. 25, 1945, p. 450.

Theoretical Analysis of Base Drainage.—Ingenious simplifications of the actual conditions have led Mr. Casagrande to conclusions in many respects similar to those of the theory of consolidation. The writer has followed the derivations of the paper and has obtained the same results as given by Eqs. 6 and 8. As to the sloping base, the writer notices that the value of the "slope factor" S as given by Eq. 10 tends to become infinite when $\tan\alpha = 0$, that is, when the base becomes horizontal. In other words, Eqs. 11 and 13 should become Eqs. 6 and 8, respectively, for the case $S = \infty$. Apparently some more mathematics is needed to clarify the infinite solutions obtained by such an operation.

Discussion of Theoretical Results.—The action of a base drain as depicted in Fig. 18 is similar to the action that prevails in pumping test. At the beginning of the pumping test the water level falls towards the pump steeply; hence both the hydraulic gradient and what may be called the effective cross section of the stream are considerable but decrease rapidly. An analogous although schematized pattern is presented in Figs. 2 and 3. Hence, the action of a drain removing water from a saturated subgrade is more or less efficient in the beginning of the drainage process only and slows down rapidly. After a certain interval of time the drainage process takes so much time that, before the value of the "degree of drainage" reaches a high value (say, 90%), a new saturation is possible. Therefore, what is called the second part of the drainage process in the paper is not essential in practice. This point of view is implicitly shared by the authors themselves when, in their final recommendations for the design of base drains, they do not extend their study beyond half of the drainage process (Eq. 15).

The authors rightly state that the present development of mathematical tools does nor permit a rigorous solution of the problems of unsteady (transient) flow. Approximate solutions with a high degree of precision have been obtained in particular cases, however. As an example, an interesting solution of the spreading problem, in many respects similar to the base-course drainage problem, should be mentioned.[9] It is noteworthy that in the base course drainage problem the shape of the actual drawdown (saturation) line is not important for computations of seepage quantities, as may be concluded from work of Louis A. Pipes,[10] who used not only an elliptic drawdown approximation, but also a parabolic approximation; an approximation based on a horizontal free surface, and the triangular approximation similar to that demonstrated by Fig. 2. In the opinion of the writer, what is really important is the lower boundary of the base course. If the base course is saturated by water pumped from the lower strata, the subgrade is also saturated, at least at its uppermost layers (Fig. 20). Hence, the drain must remove water not only from the base course but also

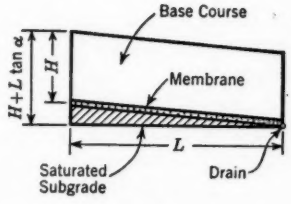

FIG. 20

[9] "Ground-Water Movement Controlled Through Spreading," by Paul Baumann, *Proceedings-Separate No. 86*, ASCE, August, 1951.

[10] "Subsurface Drainage Investigations 1945–1946. Report on Theoretical Analysis of Drainage of Base Courses," by Louis A. Pipes, Corps of Engrs., U. S. Army, Boston, Mass., March, 1946.

from the subgrade. This is possibly one of the reasons why, in such cases as that shown in Fig. 15(*b*), the time required in the second part of the drainage process in the field is much longer than the time indicated by theory.

The writer agrees with the statement that the coefficient of permeability decreases with decreasing average depth of flow. As a matter of fact the assumption of a constant coefficient of permeability is a vulnerable point in all theories of this kind, beginning with the theory of consolidation. In the drainage process, moisture is not removed from the surface of a particle in a single blow, but the particle is gradually peeled from the moisture covering it; and the closer this cover adheres to the particle, the more difficult is that peeling. Hence, a retardation of the drainage process may be expected in the soils possessing a certain value of the specific attractive power, such as silty sands in this case. The amount of moisture attracted by pea gravel is exceedingly small; hence there is practically no retardation of the drainage process in a subgrade of this material.

Theory and Laboratory Experiments.—If the subgrade is isolated from the base course by an impervious asphaltic membrane and the base course is saturated by infiltration through the pavement, the field-test results would be closer to the theory than if there were no membrane. In addition, if the coefficient of permeability is kept constant, a perfect agreement of the tests with the theory can be expected. The laboratory experiments explained in the paper precisely duplicate this particular case. As may be concluded from the paper, these experiments were performed with the utmost care, as generally all laboratory work of the Corps of Engineers, United States Army, is done; but, nonetheless, in a general case they cannot be admitted as a proof of the applicability of the theory developed in the paper.

Summary.—The work presented in this paper is a definite step forward in a relatively unexplored field and a considerable help to engineering investigators who follow and who are interested in further research along these lines. The writer wishes to emphasize that his discussion does not disregard the high value of the paper.

A. Casagrande,[11] M. ASCE, and W. L. Shannon,[12] A. M. ASCE.—Mr. Barber suggests an interesting modification of the equation for the sloping base in which a single value for the parameter c may be used for all slope factors. This permits the plotting of one set of curves in which the degree of drainage U is plotted against the time factor as shown in Fig. 19. Mr. Barber also suggests that Eq. 18 is a better solution of the steady problem of seepage with sloping base than the corresponding equation which follows from the assumption represented by Eq. 9*b*, and he bases his conclusion on a comparison with the results shown in Col. 6, Table 1. However, these results include k-values which were in part computed by Eq. 9*b* and in part derived from flow net solutions. Therefore, the values in Col. 6 cannot be used to decide which approach is more correct. Besides, the coefficient of permeability in these

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field tests varied greatly over the thickness of the layer, so that such tests would hardly be suitable for a comparison of these equations. However, viscous fluid model tests—particularly tests with steep base slopes to accentuate the differences—should be valuable for such a comparison. In the absence of such tests, Eq. 18 and the corresponding equation based on Eq. 9*b* have been compared on the basis of flow net solutions of several cases and it was found that Eq. 18 gave from 30% to more than 50% larger values for the ratio q/k than the flow net analysis, whereas Eq. 9*b* gave results for q/k which were from 5% to 20% too small. It can also be shown by simple theoretical considerations that the deviations from correct solutions should be of that order of magnitude. Therefore, the writers believe that, for the solution of steady-state flow problems with a sloping base, the assumptions in Eq. 9 are more accurate than those on which Eqs. 17 and 18 are based.

Since Eqs. 15*b* and 20 give practically identical results and since the available test data are not sufficient to prove conclusively which one is more accurate, the simpler Eq. 15*b* appears preferable for design purposes.

The writers are not in agreement with Mr. Barber on the value of dense-graded base courses, and question whether such base courses have indeed stood the test of saturation. In the writers' experience, also dense-graded bases have developed failures when they became saturated from one cause or another. Besides dense-graded bases also likely to contain, locally, an objectionable amount of fines from the standpoint of frost action.

Mr. Krynine has called attention to other possible causes for base saturation. In his discussion of the theoretical results, he notes that subsurface drains must not only remove water from the base course but also from the subgrade and that water draining from the subgrade may result in slowing down the last portion of drainage from the base course. This phenomenon might be true in some cases. Mr. Krynine suggests that this effect may have been present in the field drainage tests as indicated by Fig. 15(*b*). In these particular tests the subgrade was simulated by an impervious membrane composed of asphalt impregnated fabric (prefabricated bituminous surfacing, known as PBS, surplus from World War II) which, so far as could be determined, did not contribute to water drainage. Some troubles were experienced in making this membrane leak proof, which may have influenced the results in the opposite direction.

Although the paper has emphasized only the drainage of base courses beneath pavements, the findings are applicable to pervious subgrades where the thickness of the pervious material is limited as, for example, a sand subgrade created by hydraulic filling over an impervious formation. Assuming that in a humid climate an island 10,000 ft in diameter is created by a 20-ft-thick layer of sand on an impervious clay, it is obvious that a ground-water table in the middle of this island will remain developed substantially above the surrounding free-water level. Depending on replenishment by precipitation and on the thickness and permeability of the sand fill, the ground-water table in the fill may remain so close to the surface of the fill that it would be undesirable to build pavements upon the sand without special provisions to increase the depth from the ground surface to the water table. To provide such an

increase in depth to the water table (*a*) the thickness of the fill might be increased, (*b*) an extensive system of subdrainage could be provided, or (*c*) in the case where the sand fill is placed on a relatively thin impervious layer of clay or a silty or peaty meadow mat overlying a pervious deposit, this impervious layer could be entirely or partly removed prior to construction of the sand fill. This last method, where applicable, may achieve the desired results most economically.